CORROSION SERVICE

Stray Current Corrosion

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The ground (soils) does not confine electrical current to discrete paths in the same way as electrical cables do. It is meaningful to talk about the resistance per foot of a copper wire, but not meaningful to talk about the resistance per foot of a soil path. There is a quantity intrinsic to a material that relates the geometry of the current path to the resistance of the path.

Resistance varies directly as the length of the current path and inversely as its cross-sectional area expressed in symbols:

$$R \propto \frac{L}{A}$$

ρ is the proportionality constant such that

$$R = \rho\frac{L}{A}$$

where:
- R is the resistance in ohms
- L is the length of current paths in cms
- A is cross sectional area of current path in cms^2
- ρ is called the resistivity of the conducting material in ohms-cm

The resistivity of a material varies over very wide ranges:

e.g. Copper .... 1.6 μohm-cms
Insulator .... 10^{12} - 10^{19} ohm-cms

Soils devoid of moisture are insulators since their component grains have very high resistivities. Water containing dissolved substances is the principal conductor in the soil and the ability of a soil to conduct is a function of its moisture content. For example a red clay soil is reported to exhibit the following resistivities at two moisture levels.

5% moisture when air dried.................. 2.34×10^6 ohm-cms
22% moisture when saturated............... 6800 ohm-cms

If soil particles were spheres, a most compact arrangement would give a pore volume of 25% and a least compact arrangement would give a pore volume of 47%. In general, any moisture content in excess of about 20% by weight of dry soil has little effect on resistivity.

For man-made electrical currents to enter the ground we must have some type of connection to the earth itself. This can be a deliberately made connection such as a grounding rod at a transformer, or an accidental connection such as a broken trolley wire contacting the earth, or what is best described as a careless connection where contact to the earth is not necessary and hence not deliberately made or not accidental since no particular provision has been made to isolate the electrical conductor from the earth in the first place.

When a metallic conductor is placed in the ground, the ground connection that has been established has a certain resistance to the flow of electricity into the soil. Since the flow of electricity is not confined to any single path in the soil, it can be seen that consideration will have to be given to the nature of the resistance that occurs in this type of connection. A concept called ‘remote earth’ is required and means a location sufficiently far away from the ground connection such that it is not influenced by this connection or any currents emanating from it. If one were to consider a volume of earth surrounding a ground rod of sufficient size to incorporate the total resistance of this connection to remote earth then this volume of earth could be called the “resistance ground” of the ground rod. Theoretically, the total resistance is not encompassed until “remote earth” is reached which could be infinitely far away but in a practical sense the sizes of these resistance grounds are not very large and depend upon the physical size of the electrode that is placed in the earth. For example, the following percentages of total resistance to remote earth of a 10' long, 1" diameter ground rod are shown together with the distance one would have to go from the rod itself to define the boundary of the hemisphere that would incorporate this percentage of the total resistance.

% of total resistance to remote earth	radius of hemisphere encompassing this resistance ground
95%	34.04’
99%	170.2’
99.9%	340.4’

It is interesting to note that if the length of the ground rod driven into the soil is doubled, the size of the resistance ground is nearly doubled. The size of a resistance ground is not dependent on soil resistivity. If 10 volts were required to discharge 1 ampere into the soil the resistance of this ground connection would be 10 ohms and 9.5 volts would drop through 9.5 ohms if one were to measure the voltage drop between the rod and a point in the soil 34.04' distant. If the resistivity of the soil doubled then 20 volts would be required to cause 1 ampere to flow and 19 volts would drop through 19 ohms in the identical span of ground as before which is the boundary encompassing 95% of the total resistance to remote earth.

The foregoing examples lead to the concept of a series of bowls of earth surrounding this ground connection; the surface of each of these hemispherical bowls would form a boundary defining a certain percent of the total resistance of the ground connection to remote earth and would, a short distance from the ground connection, be perpendicular to all the current vectors being discharged by the rod. Since to reach each of these boundaries the current emanating from the rod would have to traverse an identical resistance on its singular path and hence have dropped identical voltages which are a product of the current I and the incremental resistance r between the rod and this surface, these surfaces are therefore equipotential surfaces when current flows in these resistance grounds.

Current flow in the ground can be adduced from the measurement of voltages between ground connections and other points in the adjacent soil or between two different soil locations. Care must be taken to eliminate galvanic potentials or meter errors in taking these measurements. In areas where stray currents emanate from traction systems recording instruments are essential.

Voltage drop gradients as explained above are caused by stray currents flowing through the resistance offered by the earth path. These gradients increase rapidly as one approaches an earth connection since it is here where current paths are most concentrated. If a pipeline or other buried bare conductor 'invades' the resistance ground of a ground electrode and this electrode is either discharging or collecting current from the earth, the electrical potential on this pipe at its point of nearest approach will correspond to the potential of the equipotential surface that it touches nearest to the ground connection. Portions of this pipeline or conductor that are more remote from this ground electrode are at potentials approaching that of remote earth and hence an electrical gradient is established on this conductor that causes current to flow along the pipe or conductor either to or from the ground electrode depending on its polarity.

The discharge of direct currents from metallic structures in the soil can cause damage to these structures. This damage was first observed by Nicholson and Carlisle in 1800. They immersed wires in various aqueous solutions of acids and connected them across voltaic cells. They observed various effects such as the evolution of gases, deposition of material on the wires that were in the solution, and even dissolution of the wires themselves. These phenomena were described by the word "electrolysis". Faraday in 1833 did the first quantitative study on these phenomena and devised the nomenclature that is still employed today. The wires or 'electrodes' that were immersed in the solution were called the anode and cathode respectively. The anode may be defined as the electrode where positive charges enter the solution and the cathode as the electrode where positive charges leave the solution. The solution which carries the current is termed the "electrolyte". The actual charge carriers he called ions which consisted of atoms or groups of atoms that carried either positive or negative charges.

Faraday formulated "Laws of Electrolysis" which stated that an exact weight of metal would be dissolved or deposited when an exact amount of electrical charge (coulombs) was transferred. The amount of charge to deposit 1 gram molecular weight of a metal of valence (or charge number) 1 is 96,487 coulombs (1 Faraday). This means that currents discharging from metallic structures in the soil dissolve metals at rates predicted by Faraday. In practical terms, 1 ampere D.C. discharging from a metallic structure into the soil for a period of 1 year will dissolve various amounts of metal depending on the kind of metal involved, and its 'charge number'. For example, one ampere discharging for 1 year into the soil will dissolve 22 lbs. of steel, 24 lbs. of zinc, or 74 lbs. of lead. Although Faraday could show that these currents when falling on an electrode surface in electrolytes of specific composition would deposit identical amounts of metal this beneficial counter-reaction never occurs in the soil. Currents falling on metallic surfaces in the soil often are of benefit in that they confer either partial or complete cathodic protection to these portions of the structure, reducing or eliminating naturally occurring corrosion processes.

Electrode potentials cannot be measured by themselves but require a reference base to which they can be compared. This is analogous to the measurement of elevations which would have little meaning unless referred to a datum point such as sea level. The datum point used in the measurement of voltage gradients in the soil or structure-to-soil potentials is often the copper-copper sulphate reference electrode consisting of a copper rod immersed in a container of saturated copper sulphate solution closed at the bottom by a porous plug through which soil contact is made.

This electrode is usually connected to the positive terminal of a high resistance voltmeter and the negative terminal is connected to the buried structure being investigated. The reference electrode can be placed in contact with the soil in various locations near the structure and changes in apparent structure potential noted. With experience and proper interpretation it can be determined whether the structure is picking up or discharging stray currents; however the magnitudes of these currents can only be estimated in an indirect manner. If it can be demonstrated that the structure-to-soil potential has been made less negative than its natural potential due to the discharge of man-made currents then damage is probable.

Prevention of damage can be achieved in several ways. The designers of all equipment using D.C. current could ensure that this current cannot use the soil as a conducting path. Planners of underground metallic structures should, if at all possible, avoid placing these structures in proximity to D.C. systems that either discharge or collect D.C. current from the earth. If metallic structures must approach these D.C. systems then they should be very well coated and electrically continuous. Provision should be made to determine likely areas of future current discharge and to plan appropriate metallic paths in these areas to convey the stray current back to its source thus preventing discharges of this current into the soil with its attendant damage. It must be noted that metallic bonds alone will not carry the total discharge current. Since soil paths will always remain, the current will divide between all available paths inversely according to their respective resistances.

Parallel soil paths can be prevented from conducting damaging current by “forced drainage” in which a rectifier is installed in the bond connecting a discharge area on a pipeline to the negative of the interfering current source. Such a bond can be adjusted to carry 100% of the stray current back to its source and can be automated to adjust for changes in stray current magnitude. If the stray current patterns shows no current reversals galvanic anodes can compensate for small discharges from pipe to soil.